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Development of tool selection process for milling of pocket features

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Abstract. In modern production, three-dimensional modeling of workpieces has become a logical stage in the development of the technological process. Engineering analysis, process design, CNC mill tool path design, final inspection of products and other aspects are done basing on 3D models and have become the norm in the manufacturing industry. This research aimed at deriving mathematical tools which could be used in the process of CAM software development and modernization. Structural and process related elements can be automatically recognized on the basis of a 3D model. English literature refers to such elements as features. A set of parameters necessary for the description of a pocket design feature characteristics was reviewed. Available process solutions for CNC machining of said feature were analyzed. Special attention was given to selection of the roughing and finishing mills, as well as roughing and finishing cut strategy development. A tool parameter selection algorithm was developed for CNC milling of a pocket feature.

1. Introduction

Today, rather high attention is given to the preparation of computer based manufacturing processes of new products. Therefore, process engineers have been provided with new design tools:

First, the opportunity of 3D representation of product design. An electronic part model is a document which contains the geometrical model of the part and requirements on manufacturing and inspection (including size tolerances, roughness requirements, etc.).

Secondly, a feature-based modular representation of part design. As a result, the process engineer has the opportunity to work with compiled features (holes, pockets, faces, walls, etc.). In addition to this, the current state model of the work piece which accounts for milled features can be used in preparations for a subsequent operation or transition;

Thirdly, today's knowledge base may include proven decision-making algorithms for recognized features, including selection of tools and machining modes.

Fourthly, process engineers who apply CAM system have information on the tools and holders currently available at the work place.

Today, the ISO 14649 (STEP NC) standard [1–5] is being implemented. The intention of this standard is to ensure development of intelligent CNC machines. As per this standard, '…parts are produced from workpieces by machining of typical features, relative or absolute transitions associated

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with typical working steps set by executables during running of control program, including required tolerances and complaint tools' [6]. It is reasonable to represent part design as a set of features for the purposes of process design. A feature is a set of faces to be machined in the current working step, and its timed sizes characterize the current state of the workpiece. Figure 1 lists features which form a housing type part.

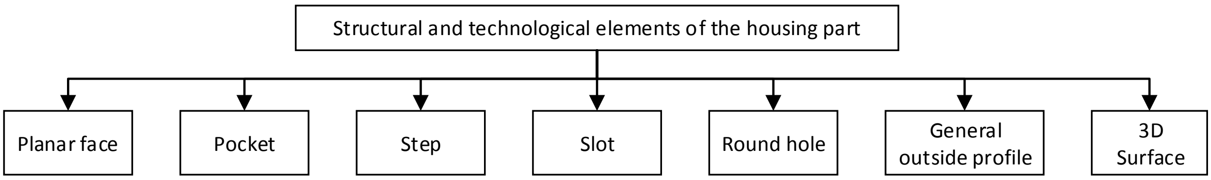
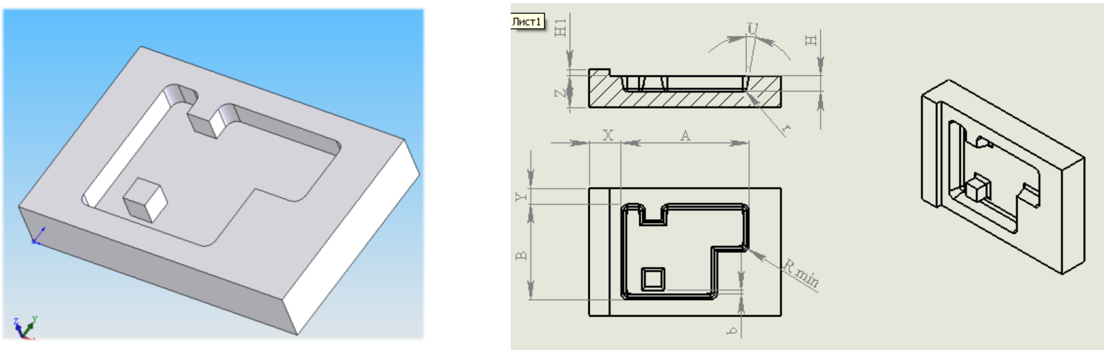


Figure 1. Structural and technological elements of a housing part.

One of the most difficult features for manufacturing process formalization is a pocket. General appearance of a pocket feature is given in Figure 2.



a) b)

Figure 2. Appearance of pocket (a) and its parameters (b).

A pocket feature has an external closed contour inside of which machining is performed. Walls of this contour may be vertical or inclined at a fixed angle. In internal contour appears when there are lugs inside the pocket. The parameter 'passage width' (b) which is the distance between the lug wall and the pocket wall, is one of the main parameters when choosing a tool. The required accuracy of desired sizes and surface roughness in the pocket determines the necessity of making finishing passes in order to ensure quality if the part being produced. In order to decide upon a pocket manufacturing process it is necessary to analyze its parameters [7].

The questions at hand in regard to parameters selection for a feature are reviewed in papers [8–13].

2. Methodology

Upon importing of a 3D model it is possible to automatically compile a list of features to be machined. This approach is used in such software as FeatureCAM from Autodesk, NX CAM from Siemens PLM Software and others.

The CAM system selects a machining algorithm basing on parameters of each feature [14]. FeatureCAM can store several system configurations setup for a milling machine. These configurations account for capabilities of the milling machine installed at the workplace, the available tools, acceptable drive loads, etc. [15]. Differences in NC for same features but under different system configurations of machines are formed at the tool path calculation stage. This is the essence of the new level of CAM system flexibility. However, the mentioned system is meant only for NC program calculation and does not provide a technological process as required by Russian state standards (unified system of technological documentation).

The main objective of this paper is development of process algorithms for machining of pocket features basing on analysis of a part's 3D model.

3. Experimental plan

As a preliminary step, let's review the options for decision making at the following stages of work:

- Choice of roughing and finishing tools;
- Choice of machining strategies at roughing and finishing stages.

3.1. *Choice of roughing and finishing tools for machining of a pocket feature*

First and foremost stage of process design for such a working step is the choice of cutting tools. In some cases one milling cutter is enough to machine a pocket. Use of additional tools is feasible in two cases:

- Strict requirements to size tolerances and pocket surface quality;
- Short radius of pocket internal corners.

Let us tackle these two cases in order.

To fulfill size tolerance and surface quality requirements the first thing to be determined should be the number of machining stages. The number of machining stages depends on size tolerance and surface roughness requirements. As stated in [16] four machining stages can be distinguished: roughing, semi finishing, cleanup, and finishing. Table 1 describes requirements to size and roughness, and corresponding milling stages.

Table 1. Milling stage depending on requirements to sizes of the part.

Milling stage	Quality class	Roughness Ra, μm
Roughing	14…12	12.5…6.3
Semi finishing	12…11	6.3…3.2
Cleanup	8…11	6.3…1.6
Finishing	8…6	0.8…0.4

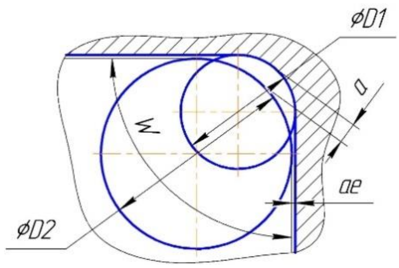


Figure 3. Relation of roughing mill diameter on pocket contour internal radius.

We will denote the roughing mill diameter as D_2, and the finishing mill diameter as D_1. Roughing mill diameter D_2 is chosen such that the tool can reach into the internal sharp corners of the contour (Figure 3) [17]. It is desired for the remaining allowance a in the internal corners of the contour to not exceed (0.15...0.25) D_1, where D_1 – diameter of tool to be used in the finishing pass. Hence, the roughing mill diameter D_2 can be determined using the equation

$$D_2 \leq \frac{2\left(a \cdot sin\frac{\omega}{2} - a_e\right)}{1 - sin\frac{\omega}{2}} + D_1 \tag{1}$$

Where a is the maximum allowance during internal corners milling, a_e – allowance for finishing milling of the contour, ω – the internal corner of the pocket.

Assuming the most general case, lets consider $\frac{\omega}{2} = 45°, a = 0.2D1, a_e = 0.3$, then, by transforming equation (1), and obtain

$$D_2 \approx 2D_1 - 2 \quad (2)$$

3.2. Choice of machining strategies at roughing and finishing stages

For roughing, one of the standard milling strategies can be chosen: zig zag, equidistant line, spiral. In our opinion, the optimal strategy here would be a spiral climb cut (Figure 4), as it ensures a good chip formation during climb cutting.

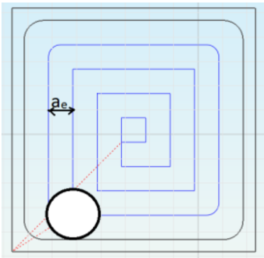
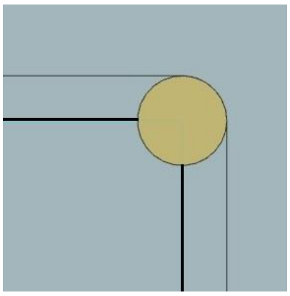


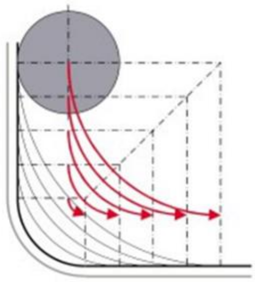
Figure 4. Application of the spiral climb cut strategy for roughing.

Recommended spiral pitch in the pocket bottom can be taken as a_e = 0.6–0.8D when the milling path max a_p = 0.3 – 0.5D depending on the material being machined.

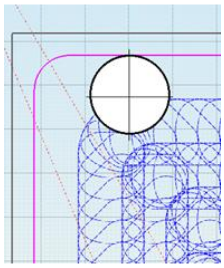
For the finishing stage the semi finishing milling scheme should be considered (Figure 5).



a) conventional method



b) layered milling with narrow contact spot



c) trochoidal milling

Figure 5. Pocket corners semi finishing milling schemes.

Conventional method (Figure 6 a) seems much easier but demands sequential decreasing of the feed as the tool cuts into the corner of the contour which increases machining time of finishing. Besides this, in such a case reliability of the finishing mill cutting is not assured due to a larger contact arc of the cutting edge with the work piece surface. Thus, currently methods (b) and (c) are considered more prospective, as they can be used even with correlation of tool diameters of $D_2 \geq 2D_1$ [18].

Trochoidal milling (Figure 6 c) is widely used for milling narrow slots and grooves, including pocket corners, to ensure a consistent depth of cut a_e. This method is especially effective in high speed milling when the milling width is chosen to be minimal a_p = 0.5–1 mm. In the context of the task of sequential milling of pocket features by roughing and finishing cuts, the layered milling with narrow contact can be recommend. Here, when material is removed from the contour corners as shown in Figure 6 b milling is performed layer by layer from $a_p = 0.5D_1$.

Feature milling algorithms must consider requirements to size tolerances and quality of surface to be milled. For instance, paper [19] provides an analysis of strategy impact on milled surface roughness. In our case of strict quality requirements to surface finish application of a finishing mill is mandatory. Additional roughing tool D_3 may be applied in cases when the area of the pocket is too large in relation to the projected area of the chosen milling cutter D_2.

4. Results and discussion

The proposed correlations can be transformed into mathematical form using the algorithm given in Figure 6.

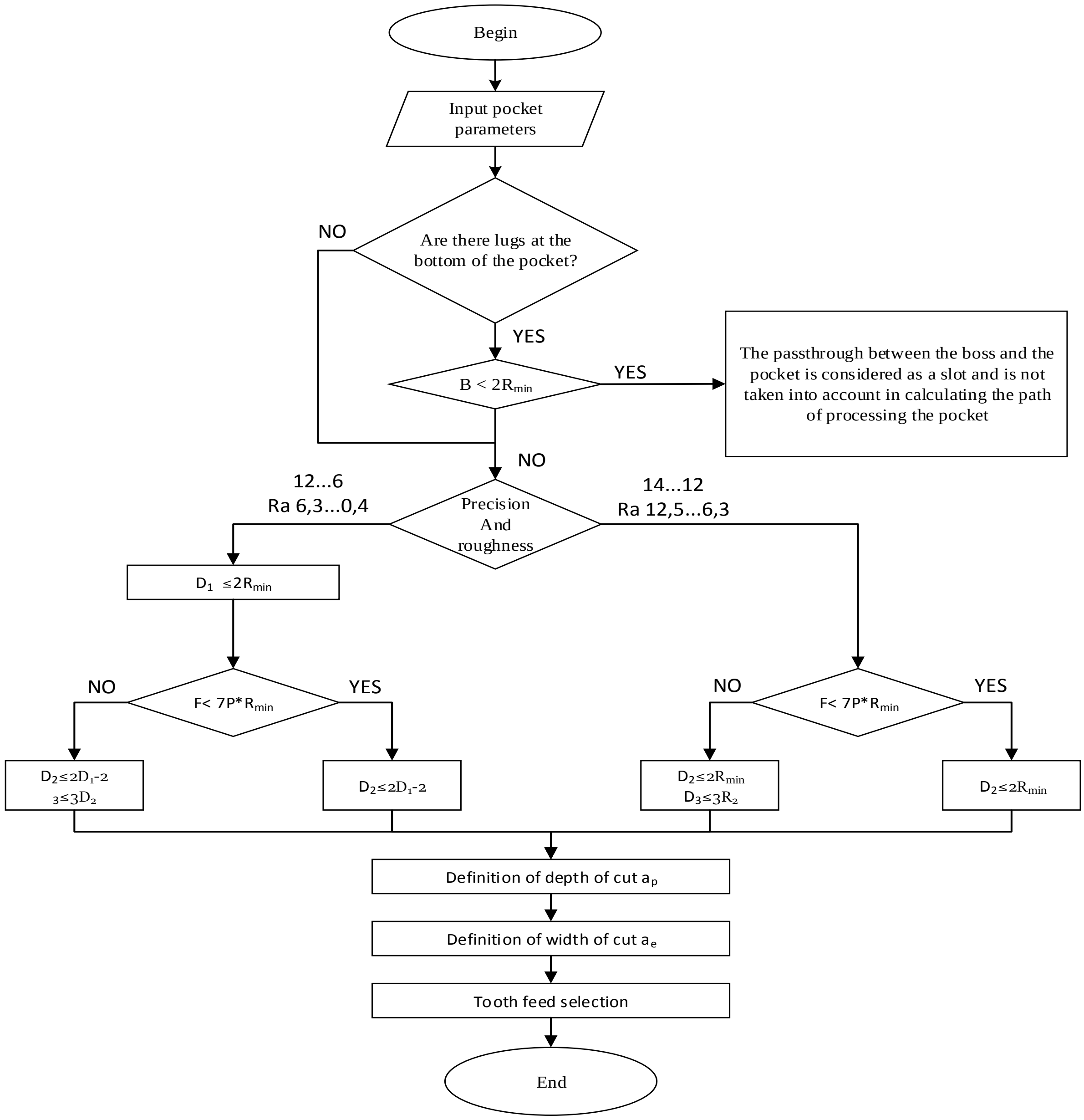


Figure 6. Algorithm for choosing roughing and finishing tools for machining of pocket features.

5. Conclusion

As a result of this research an algorithm for choosing roughing and finishing tools for machining of pocket features in the part milling modeling process in CAM systems has been proposed.

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References

[1] ISO 14649-10 2003 *Industrial automation systems and integration physical device control-data model for computerized numerical controllers-part 10: General process data*

[2] *STEP-NC System. In: Theory and Design of CNC Systems* 2008 Springer Series in Advanced Manufacturing. Springer (London)

[3] Hardwick M, Zhao Y, Proctor F M *et al* 2013 A roadmap for STEP-NC-enabled interoperable manufacturing. *Int. J. Adv. Manuf. Technol.* **68** 1023–37

[4] Kramer T and Proctor F 2009 Feature-based Process Planning Based on STEP *Advanced Design and Manufacturing Based on STEP* (London: Springer) 23-48

[5] Zhang Y, Liu Y and Bai X 2010 The Research on the Intelligent Interpreter for ISO 14649 Programs *Advances in Computation and Intelligence. ISICA 2010. Lecture Notes in Computer Science* **6382**

[6] Sosonkin V and Martinov G 2008 *Programming CNC. Tutorial* (Moskow: Logos)

[7] Kugaevsii S S 2010 Application of the method of element-wise technology for calculating control programs in a CAM-system environment *CAD/CAM/CAE-observer* **5** 65–8

[8] Ridwan F, Xu X and Liu G 2012 A framework for machining optimisation based on STEP-NC. *J. Intell. Manuf.* **23** 423–41

[9] Yamada H, Tanaka F and Onosato M 2006 Analysis of ISO 6983 NC Data Based on ISO 14649 CNC Data Model *Knowledge Enterprise: Intelligent Strategies in Product Design, Manufacturing, and Management. PROLAMAT. IFIP International Federation for Information Processing* **207**

[10] Janusz P and Sergiusz S 2017 Extension of STEP-NC data structure to represent manufacturing process structure in CAPP system *27th Int. Conf. on Flexible Automation and Intelligent Manuf.*

[11] Zhao Y, Habeeb S and Xu X 2009 Research into integrated design and manufacturing based on STEP. *Int. J. Adv. Manuf. Technol.* **44** 606

[12] Mokhtar A, Xu X and Lazcanotegui I 2009 Dealing with feature interactions for prismatic parts in STEP-NC. *J. Intell.Manuf.* **20** 431

[13] Wang J and Shu Q 2010 STEP-NC Based Manufacturability Evaluation *Proceedings of the 6th CIRP-Sponsored Int. Conf. on Digital Enterprise Technology. Advances in Intelligent and Soft Computing* **66**

[14] Kugaevsii S S 2009 On the issue of flexibility and efficiency of production preparation for CNC machines *CAD and Graphics* **12** 72–4

[15] Kugaevsii S and Titov I 2008 Development of a FeatureCAM database reconciliation module with an enterprise tool database *CAD and Graphics* **5** 66–9

[16] Pashkevich M 2010 *Engineering Technology. Course and diploma design: a training manual* (Minsk: Grevcova) p 400

[17] Safragan P 1974 *Operation of numerically controlled machines* (Kiev: Equipment) p 308

[18] *Website of company 'Sandvic Coromant'* Available online: https://www.sandvik.coromant.com/en-gb/pages/default.aspx (accessed on 01.06.2020)

[19] Firman K and Xun Xu 2012 Development of a surface roughness predictive model for STEP-compliant machining optimization *International Journal of Computer Aided Engineering and Technology (IJCAET)* **4** 206–28